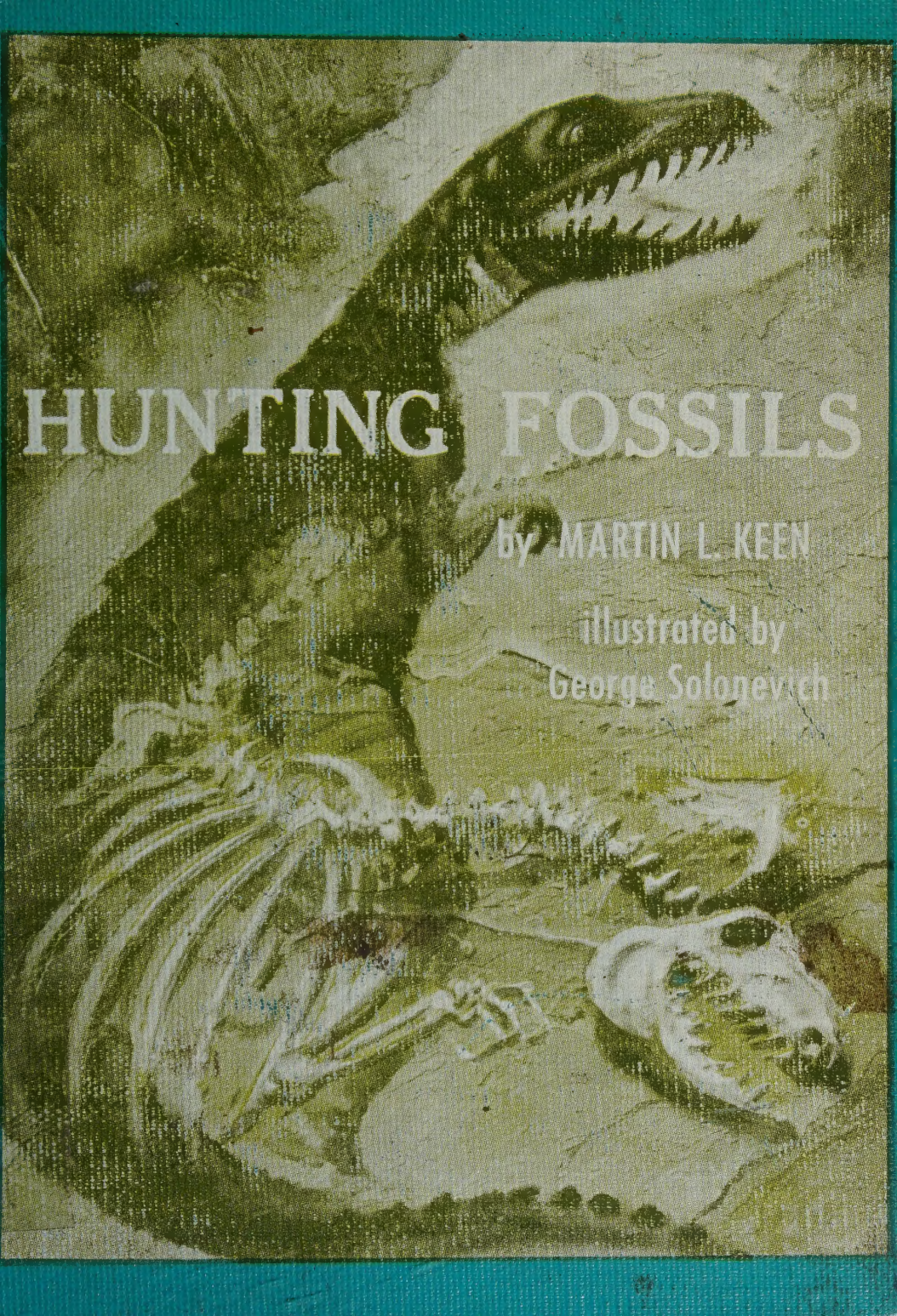
HUNTING FOSSILS
by MARTIN L. KEEN
illustrated by
George Solonevich

HUNTING FOSSILS

by MARTIN L. KEEN

Illustrated by George Solonevich
and with photographs

One day, millions of years ago, it was pouring rain. Two dinosaurs were locked in battle on a soggy hillside when suddenly the earth gave way and buried them under tons of mud. Years passed and the earth, air, and wind worked the mud into stone and forced the remains of the dinosaurs close to the surface. A hundred and forty million years later, a boy chasing a rabbit found the bones.

These bones are fossils. Fossils are traces of the remains of animals and plants that lived in prehistoric times. These fossil traces, found in different layers of rock, contain clues to the past parade of life on the earth's surface when the earth, mountains, and seas were forming. Scientists decipher the messages in rocks just as a detective solves mysteries.

The author enthusiastically describes the kinds of rocks in which fossils can be found, the eras with which they are identified, the ways nature makes a fossil, and how we can determine how old a fossil is.

If there is a fossil site near you, the author's tips will show you how to locate the fossils and how to take them out of the earth. Lists of books, museums that display fossils, and where to write for further information are additional aids for the young person making his first explorations into this intriguing field. George Solonevich's illustrations combine scientific accuracy with drama to capture life in the far distant past.

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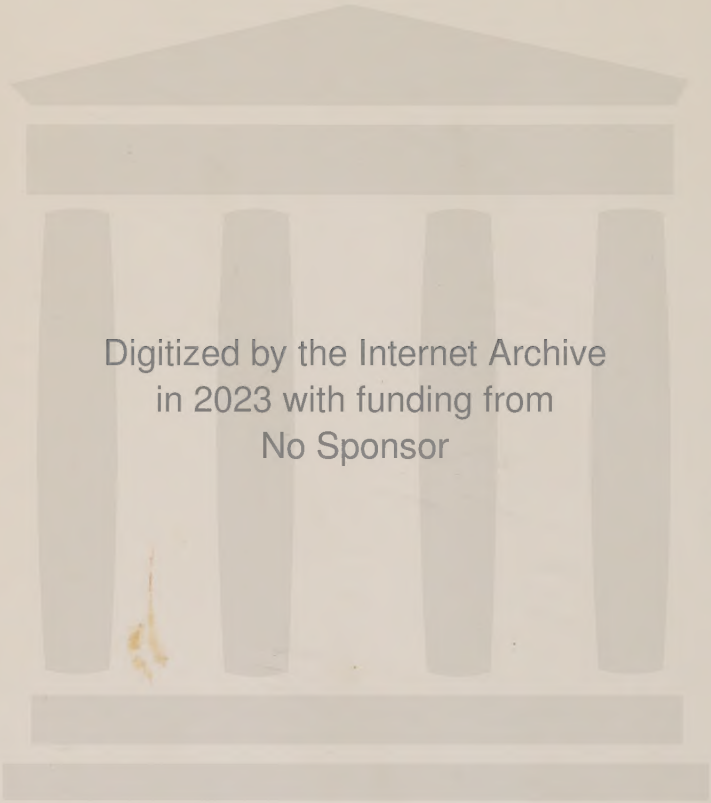
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HUNTING FOSSILS

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MICHELE, dainty, twinkle-eyed, nose-wrinkling, little lady—strong-willed, tireless busybody of a granddaughter—this book is for you, with love.

BOOKS BY MARTIN L. KEEN

Hunting Fossils
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Let's Experiment

HUNTING FOSSILS

1 TWO FOSSILS ARE MADE

One day 140 million years ago, it was raining hard. It had been raining for days, and the ground was soggy.

An enormous animal, twenty feet long from nose to tail, was browsing on the leaves of trees not far from the top of a grassy hill. The animal was a dinosaur. Dinosaurs were large, lizard-like creatures that once lived on the earth in great numbers. This dinosaur's huge body was supported by thick legs, much like the legs of an elephant, but larger. The dinosaur needed strong legs because it weighed ten tons, about as much as two large African elephants.

It had a long, powerful tail that rested on the ground. At

the end of the tail were four long, horny spikes. At the front end of the body was a short neck, a small head, and a stubby, birdlike beak with a horny covering. The whole body was protected by a thick, leathery skin covered with large warts. And, strangest of all, two rows of big bony plates stuck upright from the dinosaur's back, all the way from the neck to the end of the tail. Some of these plates were two feet high and two and a half feet wide, as big as window panes. This monstrous dinosaur was a stegosaur. Its name means "covered lizard."

Walking through the trees at the top of the hill was another dinosaur. It was even more gigantic than the one browsing. It was an allosaur, and its name means "different kind of lizard." The allosaur was about thirty-five feet long and weighed more than fifteen tons. Unlike its browsing cousin, the allosaur stood upright on two very powerful hind legs and balanced on its tail in the manner of a kangaroo. Its two forelegs were more like arms. They were much smaller than the hind legs, but were powerful nonetheless. Like the hind legs, they were armed with large, sharp claws. The head of the allosaur, held twelve feet above the ground, was huge, and its very strong jaws had two rows of big sharp teeth. Allosaurs were the tigers of the time in which they lived. They were powerful meat eaters that preyed on plant-eating dinosaurs.

When the allosaur reached the edge of the trees, it stopped for a moment. Turning its large head from side to side, it searched for an animal to kill and eat. As soon as it saw the stegosaur, the allosaur charged upon its prey. The stegosaur hardly had time to look toward its attacker before the allosaur pounced. The allosaur's fifteen tons of bone and muscle knocked the stegosaur on its side. The power of the allosaur's

attacking rush carried it over the stegosaur and several feet beyond. By the time the allosaur turned swiftly around, the stegosaur had drawn its head and legs under its body and rolled itself into a ball, as porcupines or armadillos do when attacked. And it was lashing out with the four long spikes at the end of its tail.

The allosaur bit and tore at the tough hide of the stegosaur, but the stegosaur managed to pierce the chest of its attacker with one of its tail spikes.

The two dinosaurs had been fighting for only a minute when, with a roar, the whole soggy hillside gave way and slid downward in a great mudslide. When the mass of mud came to rest in the valley, the dinosaurs were not in sight. They had been buried under tons of mud.

As the months passed, bacteria and fungi began to devour the bodies of the two buried dinosaurs. After several years, all the tons of flesh and the soft inner organs had been devoured. Nothing was left but bones, teeth, and claws.

Meanwhile, plants had begun to grow on the hill that had been stripped bare by the mudslide. Within ten thousand years, the hillside was covered by new soil in which grass and trees grew. But the hill was just too steep to hold a heavy burden of soil. During heavy rains, there was another mudslide. It buried the remains of the two dinosaurs even deeper.

The second mudslide filled the valley and dammed up the stream that flowed through it. As a result, a lake began to form. Year after year, streams ran down from the surrounding hills, bringing silt, sand, and gravel to the bed of the lake. The weight of this material pressed down on the mud in which the dinosaurs were buried. The lower layers of mud were

squeezed together, and most of the water was forced out. In this way, the mud hardened and became solid.

Thousands of years later, the lake was completely filled with silt, sand, and gravel. The lake became a marsh, and then the marsh became dry land. Far below the dry lake were the bones of the dinosaurs.

But something had happened to them; they were no longer bones. Bit by bit, underground water had dissolved them and had replaced each dissolved bit with stony material. This stony material preserved exactly the shape of the bones, teeth, and claws.

Meanwhile, the deep layer of mud in which the dinosaurs had been buried continued to harden. Within a few million years, the mud had turned to stone.

For more than one hundred million years, the stony replicas of the dinosaur bones remained quietly buried. Then, a great disturbance began to take place in the crust of the earth. The crust began to fold. That part of the crust in which the dinosaurs' remains lay was in a vast area that was forced upward. The rise was slow, only about three inches in a thousand years. Yet, this rise was enough to push the crust up more than twelve thousand feet in the next fifty million years. But the earth did not actually rise that high. Nature's great leveling process, erosion, was at work.

Erosion is the wearing away of soil and rock by the action of running water, wind, weather, and chemical changes. Almost as fast as the earth's crust rose, erosion wore it down—almost as fast, but not quite. By the time the forces that caused the folding had spent themselves, the crust had risen only four thousand feet. The valley in which the dinosaurs had

been buried was now high up in a chain of mountains.

Although the folding forces stopped, erosion went on. Finally, 140 million years after the allosaur tried to make a meal of the stegosaur, the earth's crust had been worn down so much that the stony replicas of the dinosaurs' bones were only a few feet from the surface.

Then, one early spring day, in a place that came to be known as Wyoming, rainwater collected in a crack in a low cliff. Since it was early spring, the water froze that night. The freezing water in the crack expanded, as all water does when it turns to ice. The ice exerted great pressure on the sides of the crack, and a large piece of rock split off from the cliff. The dinosaurs' remains were exposed to view.

A month later, a boy chasing a rabbit came to the place where the cliff had split. He saw the dinosaurs' "bones." The boy ran home to tell his father about what he had found. The father went with his son to the split rock to see for himself. Returning home, the father wrote to a large university. A famous scientist came to look at the dinosaurs' remains and became very excited. Later, a group of scientists arrived and very, very carefully picked and scraped away the rock, freeing the remains. At a great museum, the "bones" were put together as they had been when the dinosaurs roamed North America 140 million years before.

The stony replicas of the dinosaurs' bones, teeth, and claws were *fossils.* Fossils are the remains, or traces of the remains, of animals and plants that lived in prehistoric times.

THE ROCKS OF THE EARTH

The story of fossils is part of the story of the earth itself. Let us see how the two are closely connected.

The earth is about five billion years old. In this great length of time, it has undergone many changes. The earth was first formed from part of a huge dust cloud in space. Scientists do not agree on whether the earth was very hot then or whether the already formed earth became very hot later. Either way, there is no doubt that early in its history the earth was a globe of hot molten rock. Sometime between four and a half and four billion years ago, the molten earth cooled enough to form a crust of solid rock many miles thick.

If a giant knife sliced through a small part of the earth's crust, it might reveal layers of rock like these, some with fossils in them.

The newly formed crust was still quite hot. And beneath the crust, the rock remained very hot and soft.

The Rise of Mountains and Oceans As the earth's crust cooled, it folded and cracked in many places. Huge masses of lighter rock, floating high upon the still-molten rock beneath the crust, formed the earth's continents. Heavier rock masses sank and formed vast hollows, which later became the beds of oceans.

As long as its surface remained hot, the earth was surrounded by a layer of clouds several miles thick. Rain fell upon the hot, rocky surface and boiled into the atmosphere as steam. Then it cooled, forming droplets of water. These drop-

lets eventually formed rain clouds again. Later, as the earth continued to cool, its surface temperature fell below the boiling point of water. Rainwater, remaining upon the earth, ran in streams and rivers to the low places, where it formed the oceans.

The Rocks No one knows what kind of rock made up the earth's crust when it first formed. Geologists (scientists who study the earth) do not believe that any of the original crust has ever been seen. If any remains, it is buried deep under newer rocks. The surface of the earth now is a vast patchwork of many kinds of rocks. Geologists have divided them into three main kinds: *igneous, sedimentary,* and *metamorphic.*

Igneous rocks are those that once were molten. They come from a great reservoir of molten rock called *magma,* which is everywhere beneath the earth's crust.

From time to time, huge masses of magma slowly push up into the crust. The rising magma may come to a halt not far from the surface, and then cool and harden. Millions of years later, the crust above the cooled magma is worn away by erosion, and a great mass of igneous rock is exposed to view.

The rising magma may encounter weak places or large cracks in the crust. When this happens, the magma pours out upon the earth's surface. This can occur either in the eruption of volcanoes or as huge flows through long cracks, or fissures. Magma escaping from beneath the crust is called *lava.* The cooled lava forms igneous rocks. A large part of what is now the states of Oregon, Washington, and Idaho is covered by immense flows of lava.

There are several different kinds of lava, and each provides a different kind of rock-forming material, or *mineral.* Most rocks are combinations of two or more minerals. Quartz and feldspar are two common igneous-rock forming minerals with which you probably are familiar. Granite and basalt are the two most abundant igneous rocks.

But very few fossils are found in igneous rocks. Lava is so hot that it destroys any parts of plants or animals with which it comes into contact.

Sedimentary Rocks On the surface of the earth all kinds of rocks are eventually worn down, dissolved, or broken into small pieces. This erosion is caused by the action of weather, moving water, glaciers, wind, and gravity. Rainwater, streams, and rivers carry the small particles of rock to the lowlands and eventually to lakes and seas. These rock particles are called *sediment.* Silt, clay, mud, sand, and even gravel are several different kinds of sediment.

Sediment piles up in the lowlands when rivers flood. It piles up on the bottoms of lakes and in the sea at the mouths of rivers. In some places, sediment has piled more than ten miles thick. To reach such thickness, the piling-up process had to go on for millions and millions of years.

When sediment is piled to great thickness, the upper layers exert tremendous pressure on the lower layers. Pressure on sediment also comes from folding movements of the earth's crust. If the sediment is composed of fine particles, such as silt or clay, the pressure squeezes the water from between the particles. This cements them together and forms solid rock. If

the particles are coarse, as are those of sand and gravel, water trickles between the particles depositing minerals. These minerals cement the particles together, forming rock. Rocks formed in this manner are *sedimentary* rocks.

Rock grains are not the only source of sedimentary rocks. Some originate in chemical processes. Vast areas of the earth are covered by a sedimentary rock called *limestone*. The chemicals that make up limestone are dissolved in water when weather—rain, heat, and cold—acts on certain kinds of rocks, slowly destroying them. Water carrying these chemicals flows into water containing certain other chemicals; the chemicals combine and form a limelike substance, called *calcium carbonate*. This substance, in the form of very small particles, sinks to the bottom of still water. Chemists say that the calcium carbonate *precipitates* out of the water. Eventually, the pressure of many layers hardens the calcium carbonate, changing it to limestone.

There is another way in which limestone can be formed. Corals and certain microscopically small animals take calcium carbonate from seawater, and use it to form their skeletons. When these animals die, their skeletons accumulate on the sea bottom. In millions of years, the layers build up thousands of feet thick. Eventually they are transformed into the kind of limestone you know as chalk.

Coal is a sedimentary rock composed of partially decayed plant remains.

This table shows the most common sedimentary rocks and what materials they are composed of. These rocks are the most promising sources of fossils.

THESE MATERIALS MAKE UP	THIS KIND OF SEDIMENTARY ROCK:
Gravel	conglomerate and breccia
Sand	sandstone
Silt	siltstone
Clay or mud	shale or mudstone
Calcium carbonate	limestone
Calcium carbonate + magnesium	dolomite

Almost all the earth's crust—95 percent—is made up of igneous rocks, but most are deeply buried. Of those rocks exposed at the earth's surface, three quarters are sedimentary. The most abundant is shale, which makes up nearly half of all sedimentary rocks. Sandstone is next, making up about one third, and then limestone, a little less than one fourth.

Since sedimentary rocks are the chief source of fossils, a fossil hunter should be able to recognize the most common sedimentary rocks. This takes study, but if you want to be a successful fossil hunter, the effort will be worthwhile. For help, see Appendix A of this book.

Metamorphic Rocks When magma pushes up into the earth's crust, the rocks in its path and those nearby are put under great pressure and are heated to a very high temperature. As a result, they are changed to rocks of a different kind. Rocks formed this way are called *metamorphic, or* "changed-form," rocks. For example, when magma pushes up into limestone rock, the limestone is changed to marble. Shale transformed in this manner becomes slate.

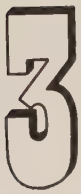
There are some fossils in metamorphic rocks. These fossils are mainly those of shells, because shell can withstand the heat and pressure that make a metamorphic rock. The next time you go to a public building, look closely at its walls or pillars. If they are of marble, especially the darker colors, you may find some fossil shells in the marble.

The Record of the Rocks Those who know how rocks and fossils have been formed can learn much about the history of the earth by studying rocks in many parts of the world. Suppose that, looking at the side of a cliff, you see a layer of basalt, an igneous rock, at the bottom of the cliff. Resting on the basalt is a layer of shale, a sedimentary rock formed from clay or mud. And on top of the shale is a layer of limestone, which forms in shallow seas. You know that the lowest layer had to be formed first, and that the layers above formed later, with the uppermost layer last. (There are rare exceptions to this rule; in some places the folding of the earth's crust has turned layers of rock completely upside down.) The basalt tells you that molten rock once flowed over this area. The shale tells you that, after the molten rock had cooled, it was covered by a lake or river. The limestone shows that, still later, a shallow sea covered the same area.

Sedimentary rocks can reveal approximately how long it took for them to be formed. For example, geologists have learned how long it takes for different kinds of sedimentary rock to form in certain thicknesses. Suppose it took twenty thousand years to form one foot of shale; if you find a cliff made of shale two hundred feet high, you know it took four million ($20{,}000 \times 200$) years to form.

Rocks reveal a record of life as it appeared throughout the history of the earth. It has been billions of years since the first living things left their fossil record in rocks. During that time one kind of plant and animal succeeded another in an unbroken line of living things. Not only did the earth's crust undergo vast changes, but the climate throughout the world changed greatly many times, and so did other living conditions. There were mild wet periods, hot dry periods, and long periods when sheets of ice covered much of the earth. These changes wiped out thousands of kinds of plants and animals, but *at no time was all life destroyed.* Life continued in other thousands of kinds of plants and animals that changed successfully to meet the new climates and the other living conditions.

All these things are parts of the story that may be learned by studying the record in the rocks.



THE PARADE OF LIVING THINGS

No one knows how life began on earth, but some scientists have thought out possible ways this could have happened. One scientist is Dr. Harold C. Urey, winner of a Nobel Prize in chemistry. Dr. Urey believes that early in the history of the earth, after the oceans had formed, the earth's atmosphere was different from what it is today. At that time, the gases making up the atmosphere were mostly hydrogen, water vapor, methane, and ammonia. Hydrogen is a chemical element, the lightest one. Water vapor is water in the form of a gas. The liquid ammonia your mother buys in a bottle is made up of ammonia gas dissolved in water. Methane, which is also

called marsh gas, makes up the bubbles you sometimes see rising from the mud of a marsh. This methane comes from rotting plants buried in the mud.

Dr. Urey thinks that lightning and certain rays from the sun broke up the ammonia and methane into the molecules that makes up these gases. These molecules and those of hydrogen combined with water vapor to form larger molecules of a kind that are found in all living things. The large molecules in turn dissolved in the ocean and then recombined in a new way, forming molecules of protein, a substance also found in all living things. In about a billion years, the protein molecules formed living matter. From this living matter eventually came all plants and animals, including man.

When did the protein molecules make up the first living things? No one knows, but it happened more than three billion years ago. In 1965, Dr. Elso Barghoorn of Harvard University found fossils of microscopic cells in South African rocks that were more than three billion years old. Ancient as these fossils may be, they are not remains of the first living things. Dr. Barghoorn estimates that the first living matter formed in the sea about half a billion years earlier. So, life on earth may be more than three and a half billion years old.

How Much Is a Billion? When you read that the earth is probably five billion years old and the first living things appeared three and one-half billion years ago, do you really know how long ago that was? Can you understand how much a billion is? Let us try to realize what these big numbers mean.

Suppose that a ten-year-old boy were to begin counting at the rate of two every second. (Try counting at this rate so

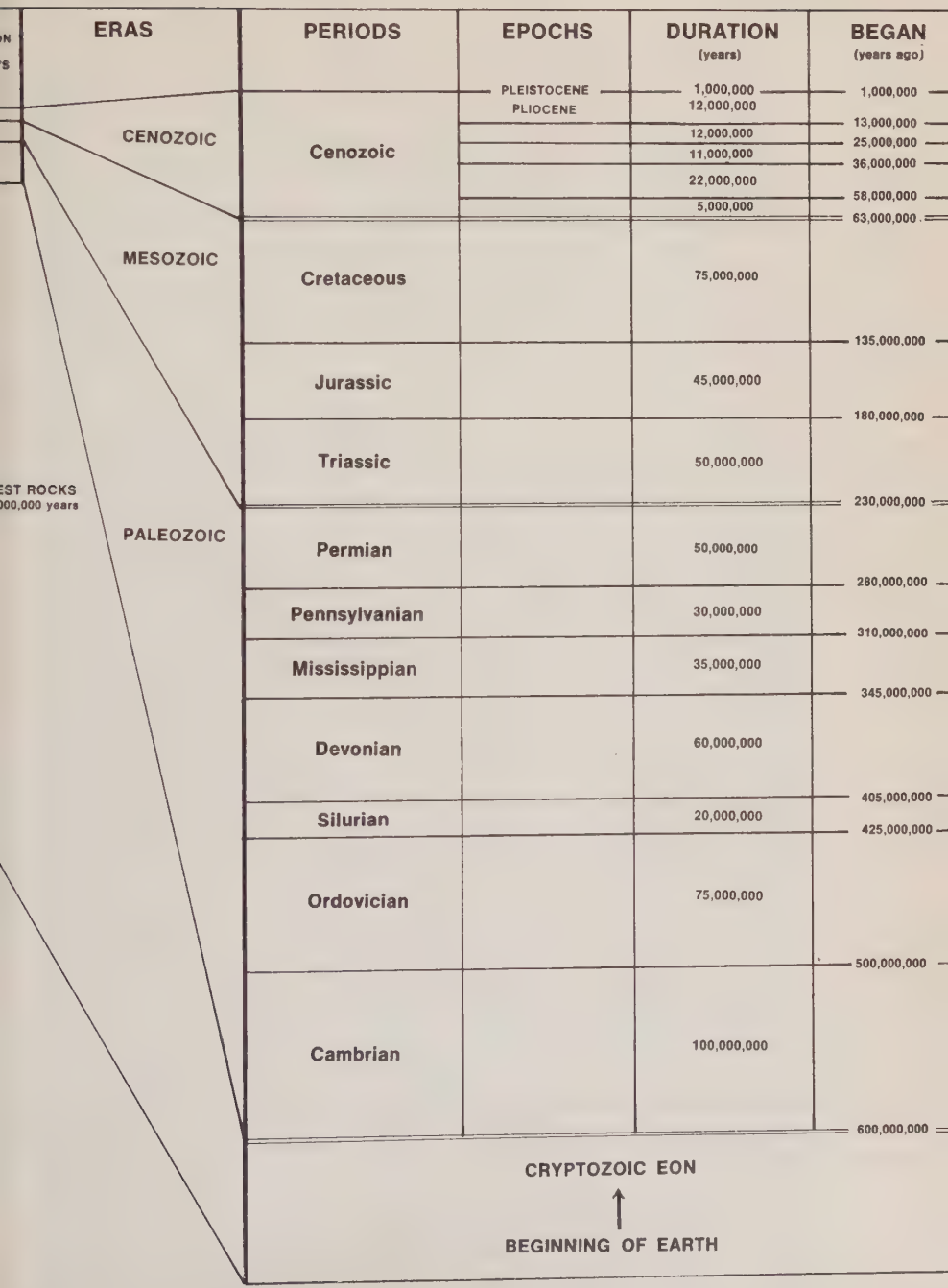
that you will know how fast the boy counts.) And suppose that this boy were to count for eight hours a day—four before lunch and four after lunch—five days a week, and fifty weeks a year. If the boy's tenth birthday fell on a Monday, and he began to count on that morning, he would not reach one million until Wednesday morning of the fourth week of his counting. He would have to count for not quite eight months before he reached ten million. He would be nearly seventeen years old by the time he had counted to one hundred million. Before he reached a billion, he would be long past the time when most persons retire from work. He would not say the words "One billion" until the third month of his eightieth year.

When you read about large numbers of years, remember that it would take you more than your whole lifetime to count some of those numbers. That may give you some understanding of the vast span of the earth's history.

The Divisions of the Earth's History To locate events in the earth's long history, geologists have divided the past into several units. As you read about these units, look at the chart on page 27. You will see four main divisions called *eras*. How did geologists decide upon the length of an era?

There have been times when great changes took place in the earth's crust. Strong and widespread folding formed mountain chains rapidly. At the same time, an increase in the number of active volcanoes also built mountains rapidly. ("Rapidly," in the history of the earth, means a few million years, instead of twenty million or more.) These times of rapid mountain building in many places are called *revolu-*

DIVISIONS OF THE EARTH'S HISTORY



tions. The span of time between two revolutions is an era.

During each era, smaller foldings of the earth's crust formed mountains and highlands. Erosion wore the high places down to sea level, and the oceans flowed over the continents, forming shallow seas. Then, the land began to rise again, and the seas flowed off the land. This series of events took place time after time, and each series is called a *period.*

Each of the events within a period—the folding of the earth's crust, the advance of the seas, and then their retreat—marks an *epoch.* You may wonder why the chart shows epochs in only the most recent period. This is because geologists have found it too difficult to identify all the epochs in earlier periods.

The Time of Hidden Life Fossil remains of plants and animals that lived between the time when life first began and seven hundred million years ago are very scarce. This does not mean that there were very few living things in those 2,800 million years. It means that very few of the older fossil-bearing rocks have ever been seen. The sedimentary rocks that formed during this great span of time have been buried too deeply by igneous rocks or newer sedimentary rocks. Those very ancient rocks that Dr. Barghoorn found are among a small number of rare exceptions.

Because this period in the history of the earth lacks fossils, it is called the *Cryptozoic Eon.* Cryptozoic means "hidden animal life," and an eon is a long span of time of no exact length. Of course, there were not only animals but also plants in those early years. So, the Cryptozoic Eon is the time of hidden plant life, too.

Plants Were First Fossils found in rocks seven hundred million years old still reveal only simple living things such as algae. You know algae as seaweed or the green scum you often see on the surface of a pond. Algae also make up the slimy emerald-green covering on the shady side of trees and rocks. Algae are single-celled plants which contain *chlorophyll,* the substance that gives plants their green color. Chlorophyll enables a plant to manufacture its own food when the plant is in sunlight.

A fossil of algae that lived more than a billion years ago and probably were the first kind of plants.

The presence of green plants in the seas of the Cryptozoic Eon was very important in the history of living things. It meant that there could exist on earth other kinds of living things—those unable to manufacture their own food. These could exist by eating plants. Animals do this. No kind of animal makes its own food. All animals must eat plants, or other animals that eat plants. Because plants can exist by themselves and animals cannot, we know that the first living things must have been plants.

The Time of Early Life The Cryptozoic Eon was followed by the Paleozoic Era, or "time of early life." The rocks formed during the first period of this era, the Cambrian Period, hold a great number of fossils. This means, of course, that there were a large number of plants and animals during the Cambrian Period. The animals that formed Cambrian fossils must have been developing for a long time, because they had eyes, mouths, legs, muscles, nerves, and cartilage. All these body parts are much more complicated than the single cells that made up the first living things. It must have taken a long time for living things to develop from single cells to the Cambrian animals. So, there must have been many living things in the Cryptozoic Eon. Perhaps, as paleontologists (scientists who study the life of past ages) continue to search, they will find many fossils of Cryptozoic animals.

The Great Parade Fossils are found in the rocks of the Cambrian Period and in all the other rocks since that time. They tell the story of a great parade of living things that swam in the seas and roamed on the land. Thousands of different

kinds of plants, trees, and animals came into existence and then disappeared. Many ancient animals, big and small, looked like none living today. Some other kinds came into existence hundreds of millions of years ago and are still living today, their forms unchanged.

All these living things have told their stories in fossils. On the following pages are pictures of many of the earth's great parade of living things. Along with the pictures of those that lived in each period of earth history are the stories of what happened in that period.

This is the fossil skeleton of a featherless, winged reptile of the Triassic Period. The muscles to which its wings were attached were not strong enough to enable it to flap its wings. Therefore, it glided rather than flew through the air.

Life began in the seas more than three billion years ago. Half a billion years ago, all animals and plants still lived in the seas.

At the left of the picture is a cephalopod (SEF-al-o-pod), an animal somewhat like a modern squid, except that it has a coiled, instead of straight, shell.

One of the cephalopod's tentacles lies over a long stalk with a flower-like top. This is not a plant, but a crinoid (KRIN-oyd), or sea-lilly animal.

The onion-shaped animal with tentacles hanging down is a jellyfish, very much like jellyfish living today.

The large creature swimming at the upper part of the picture is a eurypterid (YEW-rip-ter-id), or sea scorpion. One kind of its descendants may have been the first animals to live on land.

Below the sea scorpion, on the sea bottom, is a trilobite (TRY-lo-bite). These animals lived for almost 400 million years, before dying out about 230 million years ago. At the upper left, a trilobite is curled up and partly buried in mud, only its back showing.

Swimming away from the upper right-hand corner are two fish, which were among the first of this kind of animal.

The branched seaweed and lacy seaweed are among the plants that grew in the seas.

After remaining in the seas for about three billion years, plants and animals invaded the land. Then, in the following 175 million years, they underwent great changes.

Among the first plants to live on land were ones like those at the far left of the picture. By the end of the 175 million years, some plants had become seed bearers, like the one at the center.

The eusthenopteron (YEW-sthen-op-ter-on) at lower right was one of the first animals to live on land for any length of time. It was a fish that developed lungs with which it could breathe and strong lower fins on which it could crawl in mud.

Eryops (AIR-ee-ops) at upper right was an amphibian, a land

animal that (like the frog of today) laid its eggs and lived the first part of its life in water. Amphibians developed from fishes like eusthenopteron.

Near the end of the 175 million years, there had descended from amphibians a new kind of animal—the reptile. Reptiles could lay their eggs and live all their lives on land. Dimetrodon (DY-met-ro-don) at left was a reptile that had on its back a sail-like fin which may have regulated the animal's body temperature.

The small animals walking on two legs are thecodonts (THEE-co-dontz), a kind of reptile that was an ancestor of dinosaurs (DY-no-sawrz).

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In the next 150 million years, reptiles dominated all animals. And certain reptiles, the dinosaurs, became the largest land animals that ever lived.

Although reptiles were able to live all their lives on land, some kinds went back to living in the sea. The legs of these reptiles became fin-like and their tails became shaped like fishes' tails. One reptile that lived in the sea was the 10-foot-long, fish-eating icthyosaurus (IK-thee-o-sawr-us) at lower left.

Some of the dinosaurs that descended from thecodonts became four-footed, like the brontosaurus (bront-o-SAWR-us) at upper left. This 67-foot-long reptile, whose name means "the thunder lizard," was probably the heaviest land animal that ever lived.

Other descendants of thecodonts remained two-legged. One, the tyrannosaurus rex (ty-ranno-SAWR-us reks), or "king of the tyrant lizards," 50 feet long and 18 feet tall, was the most powerful meat-eating animal that ever lived.

At the same time that dinosaurs ruled the land, birds appeared among animals. The first of these was the archaeopteryx (ar-kee-OP-ter-iks). It had teeth like the reptiles from which it descended. It also had claws both on its feet and wings. And its body was covered with feathers.

By the end of this period in the history of living things, the modern types of trees made forests on the land.

While the dinosaurs were ruling the earth, a new kind of animal appeared among them. It was the mammal, the first animal that did not lay eggs, but whose young were born alive. About 60 million years ago, when the last of the huge reptiles died out, mammals became the rulers of the animal kingdom.

The uintatherium (yew-IN-ta-thee-ree-um) at far left was a huge rhinoceros-like animal. The megatherium (MEG-a-thee-ree-um) was a 20-foot-long sloth that could rear 18 feet above the ground to feed in trees.

The prosynthetoceres (pro-sin-THET-o-seer-es) was an elk-like animal much larger than any of the elks living today.

The wooly mammoth, which lived during the Ice Ages, looked

much like the modern elephant, but was not a direct ancestor of elephants.

One of the last mammals to appear on earth was man. This animal has been the brainiest of all and has come to dominate all other animals on earth.

A mammal important to man was the eohippus (ee-o-HIP-us), or "dawn horse." This small animal at left became larger and larger through millions of years. Its toes changed to hoofs. Finally, it became the modern horse, man's carrier and hauler of his burdens for thousands of years. See also illustration on page 80.

During the last 60 million years, cereals, fruit trees, and modern kinds of grass appeared among plants.

4 WAYS NATURE MAKES A FOSSIL

Nature makes fossils in several ways.

One thing must happen to all plants and animals that become fossils: they must be buried, either alive or soon after death. We have seen how two live dinosaurs were buried in a mudslide, but it is really very rare for live animals to be buried. Animals, being able to move about, usually can avoid live burial. Not so with plants. Since live plants are rooted in one place, they may be buried by wind-blown sand or dust, or perhaps by mud deposited upon the banks of a flooding river.

Burial is important, because it helps to preserve the plant

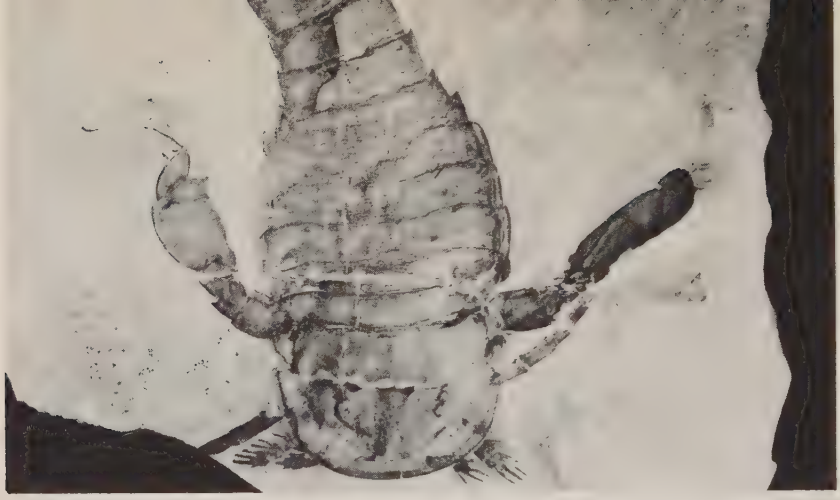
or animal from destruction, so that other fossil-making processes can begin work. Otherwise, if an animal dies on land, it may be eaten by another animal, which will break many of the dead animal's bones and scatter them about. The same holds true for animals that die in the water.

Or, if an unburied carcass (the body of a dead animal) is not destroyed by meat-eating animals, it will probably be attacked by flesh-eating insects and by certain kinds of worms. In any event, bacteria and fungi will cause the softer parts of the carcass to decay. In a short time, only the hard parts of the animal—the bones, teeth, and perhaps claws and horns—will be left. Certain chemicals in the air and in rain will act upon these hard parts, causing them to crumble, mix with the soil, and eventually disappear.

Bacteria and fungi also make plants decay and rot quite rapidly. Even huge trees may rot away completely in a few years.

When a plant or animal is buried, it is protected from destruction by animals and by air. However, some insects and worms, as well as bacteria and fungi, will still act upon the dead material, but their action will be much slower. Even these causes of decay will stop as the dead plant or animal is buried deeper. This gives other fossil-making processes a chance to work.

Most Fossils Begin Under Water Most fossils are dug out of of rock or earth that once was the bottom of a lake or a shallow sea. This is so because burial is most likely to take place in lakes and shallow seas. Many animals, such as clams, oysters, and mussels, live buried in the mud of lakes and seas.



Fossil of a eurypterid, one of the "sea scorpions"—some of them nine feet long—that dominated life in the seas of the Silurian Period, more than 400 million years ago.

When these animals die, they already are buried. This is one reason why shellfish are the most common kind of fossils.

Other animals, those that live in water all or some of the time, sink to the bottom when they die. Birds and land animals may drown and then sink to the bottom. Shortly after the death of these animals, a storm or swift current may stir up the muddy bottom. Then, when the water becomes calm and the mud settles again, the animals' remains are buried.

Heavy rains, especially spring rains, wash large amounts of soil into rivers and other streams. Swollen by rainwater, the streams run swiftly and carry soil particles as sediment, until they reach lakes and seas. Here, the streams lose speed and no longer are able to carry their loads of sediment, which settle to the bottom. Year after year, one load of sediment piles on top of another, and animal remains are buried deeper and deeper.

Turning Into Stone When the long-buried remains of plants or animals eventually become stonelike fossils, the remains are *petrified,* which means "turned to stone."

We have seen how the bones, teeth, and claws of two dinosaurs were turned to stone. Water trickled down through very small spaces in the packed sediment that buried the dinosaurs' remains. The water dissolved and carried away the bone, tooth, and claw material. This material was replaced by minerals, which were rock-making materials.

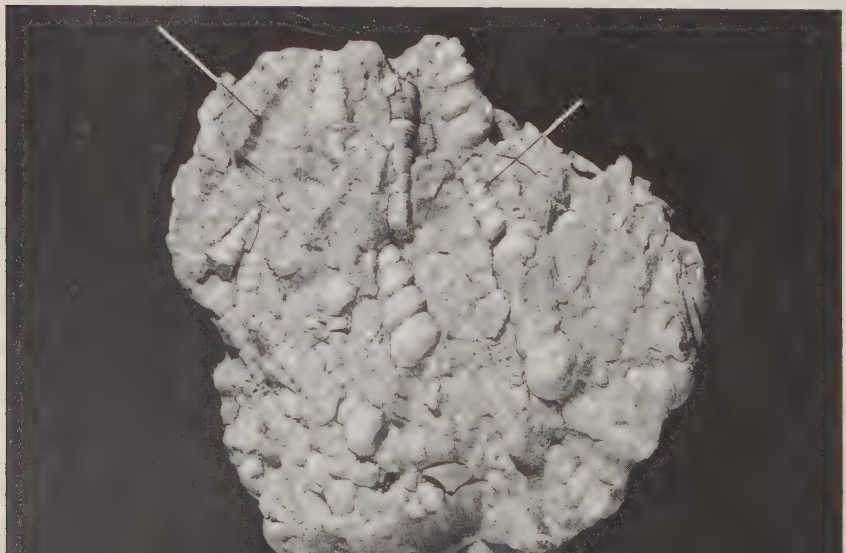
A Forest of Stone Sometimes the water that seeped through the pores of plant remains caused them to be replaced, molecule by molecule, by minerals. The fossils of plants that were petrified in this way are so perfect that you can see under a microscope the structure of the cells that once made up the living plant. The most famous example of this fossil-making

These fossil logs, in the Petrified Forest National Park of Arizona, are part of a whole forest buried 50 million years ago and slowly petrified, or turned into rock.

process can be seen in the Petrified Forest National Park, which is in Arizona. Here, floods buried a forest about 175 million years ago. Molecule by molecule, the forest became petrified. Today, in the park you can see thousands of stone logs that look like the trees buried so many millions of years ago.

Molds and Casts Underground water, trickling through the tiny spaces between the particles that make up sedimentary rocks, may completely dissolve the buried remains of plants or animals, but it will not replace the dissolved material with anything at all. This leaves a hole in the rock where the remains had been. These empty spaces are called *molds*. Millions of years later, ground water may again seep through the rock containing the mold. This time the water may carry the kind of minerals that will collect in the mold, filling it com-

The arrow at left points to a fossil mold, and the arrow at right to a fossil cast of Eocene sea snails.



pletely with a rocklike material. The filling is called a *cast*. The cast is made of a different kind of material from the surrounding rock, and is still another kind of fossil.

Which Went First? Some fossils are not made from the remains of plants or animals. These fossils are simply footprints or imprints in mud which were made by the feet and tails of animals, by leaves, and even by raindrops. These fossils were made in this way. It rained on a desert, making shallow mud. The mud began to dry, becoming thick. An animal walked across the mud and left clear-cut footprints. A few raindrops —not a heavy rain—fell on the drying mud. Each raindrop made a tiny pit in the mud. Day after day, the sun came out and baked the mud, making it hard as brick. Wind blew dust over the baked mud and filled up the footprints and raindrop pits. A year or two later, a rain shower wet the dust, making it mud and caking it in the imprints. The rains became more frequent and covered the area of the filled-in imprints with mud that, in millions of years, became rock. Then, the slow process of erosion wore the rock down to the imprints, which were now footprints and raindrop pits in rock.

There is a slab of stone in a museum of Yale University containing the footprints of a large dinosaur. Within these footprints—and all over the slab—are pits made by raindrops. Also, there are footprints of a smaller dinosaur. There are no raindrop pits in these smaller footprints. One of the dinosaurs walked across a muddy place before a light rain; the other dinosaur crossed the same mud after the rain. Can you, 160 million years later, figure out which dinosaur went first?

Coal Is a Fossil In the chart on page 27, you will see two periods of earth history labeled Mississippian and Pennsylvanian. Some geologists lump these two periods into one, calling it the Carboniferous Period, or the Coal Age. Carboniferous means carbon-producing, and coal is composed almost entirely of the chemical element, carbon. During this period, shallow seas flooded North America, and much of the land was swampy. The climate was rainy and hot. Thick forests of tall trees grew rapidly. These trees were not woody, nor were they covered with bark, as modern trees are. They were spongy and soft, and had green trunks. Some were tall tree ferns; others, fifty feet tall, were like the three-foot horsetails that grow today. Still others that grew more than one hundred feet tall looked like the less-than-one-inch club mosses of today.

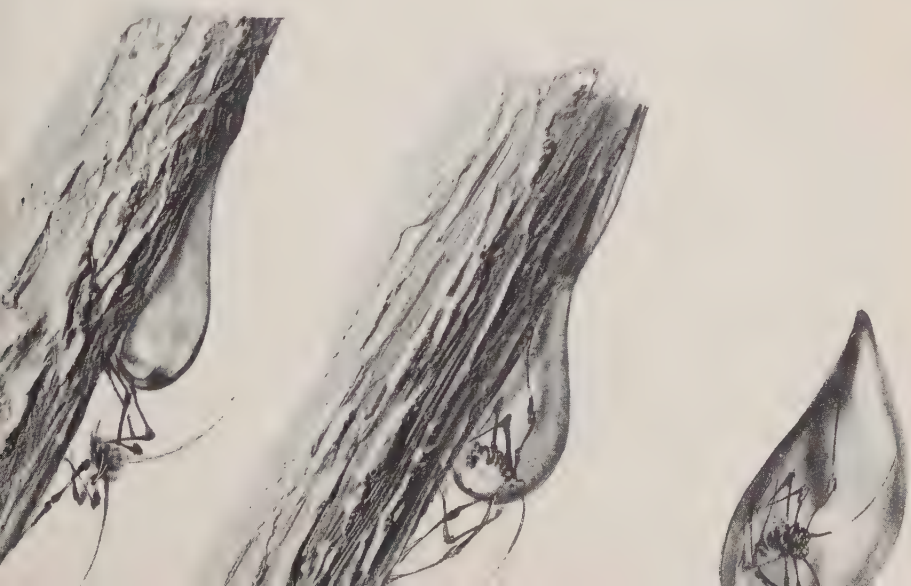
When these trees died, they fell into the swamps. The fallen trees sank into the mud. More trees died and fell upon those buried. More mud covered the newly fallen trees. In almost the same way that pressure and time changed sediment into rock, the buried trees were changed to coal.

Coal, then, is the fossil remains of huge trees that grew as early as 265 million years ago. And coal is a very good source of other fossils. If you can get an opportunity to examine lumps of soft, or bituminous, coal, you should not have to search through very many lumps before you find the imprint of a fern or a stalk or leaf of some other plant that lived in the swamp along with the coal-making trees. Less commonly, you may find the fossil imprint of an insect that flew or crawled in the same swamp. Imprint fossils are also found in hard, or anthracite, coal, but they are much rarer than in soft coal.

Insects in Amber Whole leaves and insects have become fossils by being trapped in some material that preserved them entirely. Amber is one such material. Amber, which looks like clear dark-yellow plastic, is itself a fossil. It comes from the sticky yellow pitch that oozes out of the bark of pine and other kinds of evergreen trees.

Fossils of leaves, twigs, and insects have been found in amber. These living things were caught in the sticky pitch oozing from the trunks of trees, and after a time, were covered completely. Long contact with the air caused the pitch to harden. The trees died, fell, and decayed. The hardened pitch, which is not harmed by the bacteria that cause decay, was

An insect, stuck on a drop of pine pitch, becomes completely covered. Eventually, the pine tree may become buried in the earth, the pitch turn into amber, and the insect become a perfectly preserved fossil.



buried in the earth. Eventually, the pitch became amber. And the twigs, leaves, or insects within the amber became well-preserved fossils.

Some pieces of amber containing fossils are as much as forty million years old. This means that the fossils are almost exactly like the living plants or insects of forty million years ago—not just petrified remains of these once-living things.

Fossils from Nature's Freezer One late spring day in 1905, a hunter and his dogs were walking along the tundra, the deeply frozen ground of northern Siberia. The winter had been milder than usual, and the spring had been early and warm, thawing the ground and turning it to mud. A whole low hill had become so muddy that half of it had collapsed. The dogs ran to the remaining half and began to tear at something in it. The hunter, running up, saw the remains of a huge animal on whose flesh the dogs were feeding.

The animal was a woolly mammoth, which had lived more than a million years ago. This mammoth had fallen into a crevice and had broken its leg. Unable to get out of the crevice, the huge animal had died and been frozen. Eventually, the frozen carcass had been buried by slowly sinking into the frozen mud. Bacteria and fungi cannot cause decay at freezing temperatures. So, the whole mammoth became a fossil.

Since the time this fossil mammoth was found in Siberia, other mammoths, as well as woolly rhinoceroses and other animals, have been dug out of the tundra. These frozen fossils are only about a million years old. This is not very old when compared to the hundreds of millions of years in which the ages of most fossils are measured. However, the frozen

fossils are important because they are remains found almost entirely as they were when alive. Bones, teeth, skin, hair, toenails, internal organs, and even food in the stomach were preserved.

A Dinosaur Mummy One day, about a hundred million years ago, a duckbill dinosaur died while crossing what is now the Arizona desert. Perhaps, this dinosaur, which fed on water plants, was looking for a lake or river, because the ones near which it had been living were drying up. Crossing the desert, the dinosaur died of thirst.

Wind-blown sand covered the carcass. Bacteria and fungi began the work of decaying the dead dinosaur. But bacteria and fungi need moisture in order to live, and the duckbill dinosaur was buried in very dry sand. The only moisture was that in the flesh and other organs of the dinosaur itself. A few months after death, the duckbill's carcass had become completely dried out. As a result, the process of decay had destroyed only the inner soft parts, leaving the skin along with hard parts.

A hundred million years later, paleontologists found in Arizona the duckbill dinosaur's carcass, dry and shriveled, like a mummy. The skin was leathery and very well preserved. This was a very important find because it enabled scientists to learn what the skin of at least one kind of dinosaur was like.

The Buried Forests of Yellowstone Thirty million years ago, near a valley that later became part of Yellowstone National Park, in Wyoming, a volcano erupted. It flung out a huge

blast of very hot poisonous gas which set afire the grass, trees, and bushes that grew on the sides of the volcano and in the valley below. Nearby insects, birds, and other animals were burned to death or suffocated. For months, the volcano spewed out ashes, burying the dead tree trunks and the carcasses of the other living things. The valley was filled with ash. Eventually the volcano stopped erupting and for thousands of years, it remained quiet. New trees and grass grew on its sides and in the valley. Animals, birds, and insects again lived near the quiet volcano. Then, again, the volcano erupted, killing all living things near it. This happened time after time, eighteen times in all.

Millions of years later, a river cut through the rock formed by layer after layer of volcanic ash. The river revealed eighteen fossil forests and eighteen groups of animal, insect, and bird fossils, one on top of another, like apartments in an apartment house.

The Tar Pits of La Brea In certain places of the earth, oil seeps to the surface from underground oil pools. In the open air and beneath the heat of the sun, the lighter, more liquid parts of the oil evaporate. This leaves behind a very thick, brownish-black material, which is called asphalt.

In the early part of the twentieth century, workers were removing tar from a tar pool, or tar pit, at Rancho La Brea in Los Angeles County. In the tar they found many large bones. Scientists, who were called to look at the bones, recognized them as those of a mammoth, a saber-toothed cat, a huge wolf, and a big vulture, all animals that lived a million years

ago. From the positions in which the bones were found, the scientists made a careful guess about how these fossils came to be in the tar pit.

Rains had collected on a tar pool. Tar is waterproof, and rainwater will not sink into it. The water hid the tar. A mammoth walked into the water to drink and was caught by the sticky tar. The huge, heavy animal struggled hard, but was unable to pull itself out. Exhausted by its efforts, the mammoth fell on its side. Only its head was not trapped in the tar.

Not long afterward, on the same day, a saber-toothed cat, larger than any lion or tiger living today, saw the mammoth. The big cat dashed through the water—its speed keeping it from sinking into the tar—and leaped upon the mammoth. The cat's huge claws dug deep into the mammoth's side. The mammoth reared its head and lashed its trunk at the saber-toothed cat. The trunk struck the cat a tremendous blow, knocking it into the water.

The cat, badly shaken, stood up to leap back onto the mammoth, but the leap never was made. The heavy cat, too, was caught in the tar.

The next day, a vulture, seeing the two carcasses in the pool of water, swooped down to feast on them. The big bird landed on the saber-toothed cat. But the cat was not dead. With a quick movement of its head, it caught a wing of the vulture and pulled it into the water. A week later, a huge wolf seeking to eat mammoth and tiger flesh, made the same mistake as the other animals and was trapped in the tar.

Eventually, all the four animals sank beneath the surface of the tar, which preserved them as fossils.

At the Rancho La Brea tar pit and at other tar pools, such as those in Poland, fossils of many animals have been found. Among them have been rhinoceroses, horses, and small animals, such as birds, and even insects.

5 HOW OLD IS THAT FOSSIL?

We have been reading about fossils that are tens and hundreds of millions and billions of years old. How do paleontologists find out the ages of fossils? With only rare exceptions, a fossil has the same age as the level of rock or other material in which it is found. So, paleontologists turn to geologists for help in deciding the ages of rocks.

The age of sedimentary rock can be determined by studying the layers of which it is made. Geologists have worked out, for different kinds of sedimentary rock, how long it takes a layer of a certain thickness to form. Using this information, the age of a particular rock formation can easily be calculated.

Suppose it takes an average of fifty thousand years for a one-foot-thick layer of a certain kind of rock to form. Then, suppose you find a four-hundred-foot cliff made of this kind of rock. Multiplying the number of years it took to form one foot of the rock by the number of feet of rock ($50{,}000 \times 400$), you get twenty million years, the time it took to form the whole cliff.

Now, suppose you find a fossil three quarters of the way down from the top of this cliff. You know that the sediment that made the rock below the fossil was there before the animal died. So, in order to figure out when the animal died, you must know only how long it took for the rock above the fossil to form.

Since the fossil is three quarters of the way down a four-hundred-foot cliff, it has three hundred feet of rock above it. And each foot of that three hundred feet of rock took an average of fifty thousand years to form. So, multiplying three hundred by fifty thousand, you get 1.5 million as the number of years ago that the animal died.

Actually, using layers of rock to date a fossil is not often as simple as in the example you have just read. For instance, suppose erosion has been wearing down the land of which the cliff is a part. Then, the distance from the top of the cliff to the fossil would be less than the total height of the layers of rock that had actually formed. Suppose that fifty feet had been worn from the top of the cliff before you discovered the fossil. Then, 2.5 million would be missing from your calculation of the age of the fossil.

Also, it is not usual to find a whole cliff made of a single kind of rock. Different kinds of rock form at different rates. A

foot-thick layer of limestone and a foot-thick layer of sandstone are not likely to form in the same length of time. In addition, one or more of the layers of rock making up a cliff may be igneous rock. All these facts complicate the calculation of the date of a fossil found in a layer of rock.

Moreover, it is not always easy to work out accurately how long it took a foot of a particular kind of sedimentary rock to form. However, geologists use more than one method to determine this, and so they are able to check their calculations. Also, they make comparisons of a particular formation of rock with other formations nearby and faraway. Using the several methods that they have worked out, geologists manage to get good results in dating fossils by rock layers.

The Clocks in the Rocks Another method of dating rocks is used mainly for igneous rocks. Certain kinds of rock contain chemical elements that are radioactive. A radioactive element continually emits two kinds of extremely small particles and invisible rays much like X-rays. These are given off at a rate that never changes year after year. No one knows how to speed up or slow down the rate of emission.

Uranium-238 is a radioactive element that is found in many kinds of rock. As the uranium emits the particles and rays from the nuclei of the uranium atoms, it eventually changes to the elements lead-206 and helium-4. Scientists say that uranium *decays* to lead and helium. Since the particles and rays are given off from the uranium at a constant rate, the uranium decays at a constant rate. It takes a certain number of years for half the uranium to decay. Then it takes the same number of years for half the remaining uranium to

decay, and so on. The time it takes for half of a radioactive element to decay is called the *half-life* of that element. The half life of uranium-238 is 4,560 million years. This is about as long as the earth has been in existence. So uranium is like a "clock" that "runs" long enough to measure the changes that have taken place in the history of the earth's rocks.

Uranium is heavier than lead, and both uranium and lead are much heavier than helium, which is a gas. When rock is molten—that is, so hot that it has melted to a liquid—uranium separates from the two products of its decay. The uranium sinks below the lead, and the helium evaporates out of the rock. But when a molten rock cools and becomes solid, the uranium cannot separate from the products of its decay.

Suppose that geologists analyze a sample of rock and find that for every 985 atoms of uranium-238, there are thirteen atoms of lead-206 and two atoms of helium-4. This means that fifteen of every thousand atoms of uranium have decayed. Now, one half the uranium, or five hundred of every one thousand atoms, would have decayed in 4,560 million years. So if only fifteen atoms have decayed, then only 15/500 of 4,560 million years have passed since the rock became solid. Making a calculation ($15/500 \times 4{,}560{,}000{,}000$), you find that the rock is only 135 million years old.

Almost no fossils are ever found in igneous rock, but knowing the age of a layer of igneous rock can be a big help in dating fossil-containing rocks above and below it.

Radioactive Dating of Sedimentary Rocks As we learned, the radioactive-uranium method can only be used to find the age of igneous rocks. However, there is a way to use the radio-

active clock to date sedimentary rocks. When certain sedimentary rocks, such as limestone, are formed by chemical precipitation in seas, a mineral called *glauconite* is also formed. Glauconite contains radioactive potassium-40, which can be used as a clock in the same way as uranium in igneous rock. Potassium-40 decays to the elements argon-40 and calcium-40. The half-life of potassium-40 is 1,300 million years. Therefore, radioactive potassium can be used to date fossils that were formed as early as the Cryptozoic Eon.

Rocks made from volcanic ash contain a mineral called *biotite,* which also contains radioactive potassium-40. Thus, the age of fossils buried in volcanic ash can be dated, too.

Fossils Date Rocks We have read how fossils are dated by learning the date of the rocks in which they are found. Dating works the other way around, too—fossils can help to date rocks or other fossils.

Suppose a paleontologist finds fossils of a certain kind of trilobite in a limestone cliff in Kansas. Let us suppose that the paleontologist has never seen this kind of trilobite before and, of course, has no idea when it lived. He turns to geologists for help in finding the age of the limestone. The geologists tell him that it was formed in the middle of the Ordovician period. Therefore, the paleontologist knows that this kind of trilobite lived in the middle of the Ordovician. So far, this story has not told us anything new about fossil and rock dating; the date of the rock was known and that told the date of the fossil found in the rock.

Now suppose that a Russian geologist finds fossils of the same kind of trilobite in limestone in Siberia. If the Russian

has heard about the trilobite fossils found by the American, he can now date the Siberian limestone. The trilobite he found also lived in the middle of the Ordovician, and therefore the limestone was formed at that time in the earth's history. How can he know this?

We have learned that in the long history of living things, many kinds of plants and animals have come into existence, have changed into many different forms, and, finally, have died out. But nature has never retraced her footsteps. She has never given a particular kind of plant or animal exactly the same form twice in its history. Nor have there ever been two different kinds of plants or animals that have been exactly alike. In short, each kind of plant or animal has lived during one time span only.

Fossils that can be used to date rocks are called index fossils. These three cross sections of rock may be found in three widely separated parts of the earth, but geologists know that the layers containing identical fossils were formed at the same time in geological history.

A trilobite living in the middle of the Ordovician period was different from all kinds of trilobites that had lived in the Cambrian and in the beginning of the Ordovician. Trilobites continued to live and change throughout the rest of the Ordovician, the Silurian, the Carboniferous, and the beginning of the Permian—two hundred million years more. But at no time in their long history did any kind of trilobite change back to what it had looked like in the past.

So, knowing that a particular fossil—let us call it fossil X—existed during only one particular span of time, you have a way of dating a layer of rock. No matter where in the world fossil X is found, the plant or animal that made it lived at the same time as all other fossil Xes. So the rocks in which fossil X is found in one part of the world were formed at the same time as rocks containing fossil Xes in any other part of the world. Therefore, the Russian geologist knew that the Siberian limestone and the American limestone were formed at the same time.

Fossils that date rocks are called *index fossils*, or *guide fossils*. Not just any fossil can be used as an index fossil. Paleontologists must have found enough samples of a particular kind of fossil so that they know what a typical one of these fossils looks like.

Geologists and paleontologists work hand in hand. All paleontologists are trained in geology, and all geologists understand paleontology.

FINDING A FOSSIL 6

Finding a fossil is not easy. But neither is it very difficult—if you know where and how to look.

There are billions of fossils, and some are buried in every part of the world. But this does not mean that you can find fossils by digging for them anywhere at all. That would be like trying to pitch a strike in a baseball game by wandering onto the field blindfolded and throwing the ball in any direction at all. Instead, the most practical way to find fossils is to narrow down the number of places where you look. How can you do this?

Go with the Experts First, you can go out into the field with experienced fossil hunters. Some natural-history museums have fossil-hunting programs, in which members of the staff take groups of young people on field trips. If you can, go on one of these trips. Not only will you be almost certain to find a fossil, but you will also learn a great deal: what kind of earth and rock in your part of the country is likely to contain fossils; how to recognize fossils as they look when in the earth; how fossils are taken out. If there is a natural-history museum near your home, write to its director and ask about fossil-hunting trips. Appendix B in this book lists a number of museums in the United States that have fossil collections. Some of them may have programs you can join.

If there is no natural-history museum nearby, perhaps you can get permission to go along on a college field trip made by paleontology students of a local university. Appendix C lists some of the colleges and universities in the United States that have paleontology departments.

Following Directions to the Fossils Beds Even if you have been lucky enough to make a field trip with the experts, you will want to go fossil hunting on your own. There is real fun and satisfaction in finding fossils without some expert to point them out.

The most likely way to find fossils is to look for them in locations where they are known to be buried. You can get information on fossil locations in your part of the country by writing to the geological survey of your state government. (A geological survey is a government department that employs geologists, mapmakers, and paleontologists to survey

the earth and make maps of what is on and under the surface of the earth.) Appendix D lists such departments for most of the states of the United States.

Let us suppose that you have received information from the geological survey of your state. Now, you have to learn to use it. A typical description of fossil sites might read, in part, like this:

> *Harristown: 2.5 miles southwest of Granboro, Neptune County, a few specimens of the Jurassic oysters,* Exogyra ponderosa *and* Gryphaea; *Franklin's Point, Tyrone County, many specimens of a small bony Triassic crustacean,* Diphurus, *and great numbers of Bryozoans in Ordovician limestone, in abandoned quarries along U.S. Route 40, between Franklin's Point and Greenville; Swedestown, Blair County, Devonian fossil mussels and starfish in excavations for East-West Thruway, at crossing of Penn's Creek.*

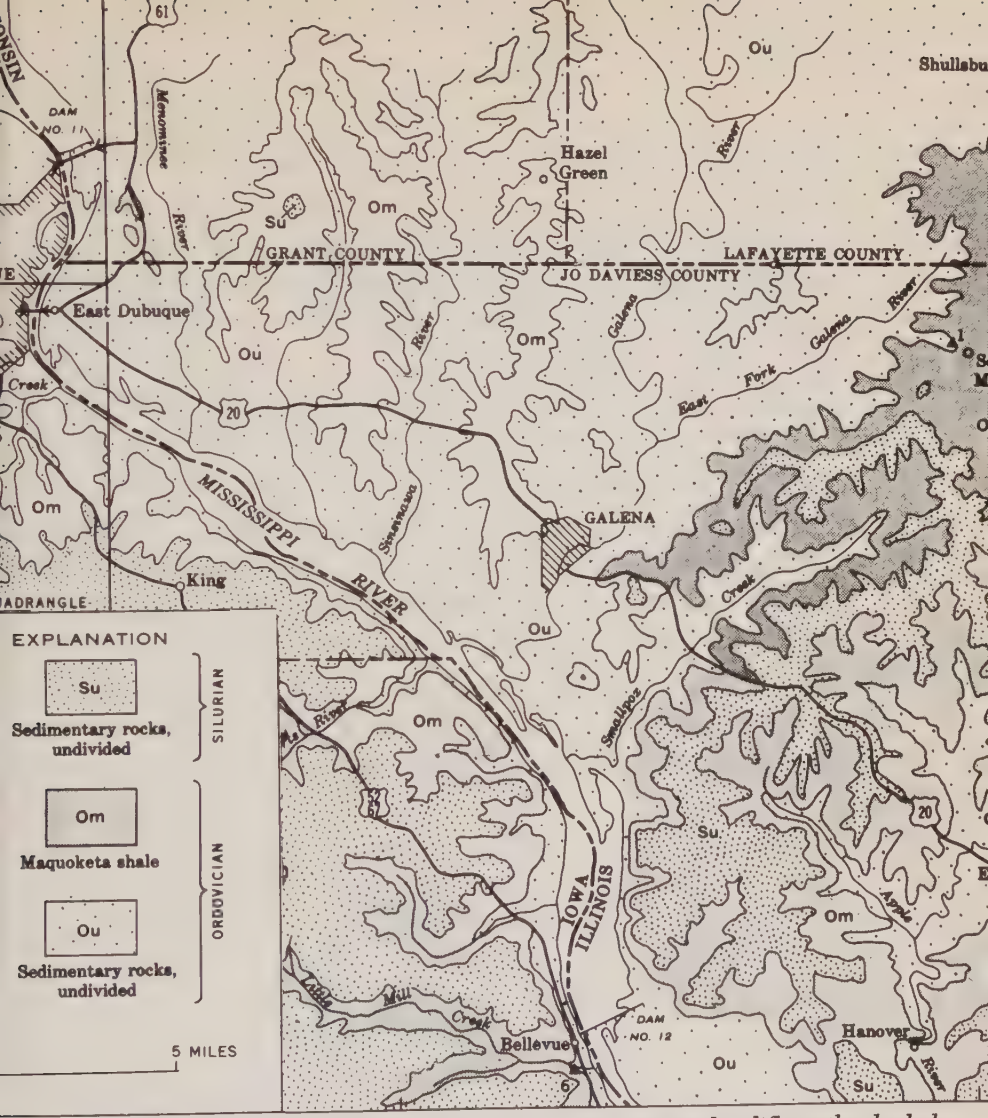
A fossil of a colony of bryozoans (a kind of sea animal) in limestone that formed half a billion years ago.

Let us go over this information and understand all of it. You will have to do this if you are going to hunt down fossils successfully.

First, Harristown is the name of the rock formation that contains the fossils. It probably got its name from the town near which the formation was discovered. To locate the Harristown formation, you will have to know what kind of rock it is made of and how to recognize that kind of rock when you see it. The geological survey of your state has maps that show all known rock formations. So, when you write for information on fossil sites, also ask for a geological map that shows the rocks in the area where the fossils are buried. Part of a geological map is reproduced on page 65. You can see that it gives names for each rock formation and tells what kind of rock makes up the formation.

The United States Geological Survey, a bureau of the United States Department of the Interior, has made excellent maps of the rocks in most parts of this country. So, if the geological survey of your state does not have a map of the area you want to search, the U.S. Geological Survey may be able to supply one. Write to the United States Geological Survey, General Services Building, 18th and F Streets, N.W., Washington, D.C. 20242, asking for a price list of geological maps for your area. Even if your state geological survey can supply maps, you would do well to get others from Washington, too.

Suppose you learn from the map that Harristown rocks are shale. You will have to recognize shale when you see it. If you have followed the advice given in Chapter 2, you should be able to identify shale and other rocks in the field.



his is part of a geological map. The letters Su, Om, and Ou on the differently shaded arts of the map locate rock formations. The kind of rock and the reason for the choice letters can be understood by reading the EXPLANATION. Take, for example, the ctangle that encloses one kind of shading and the letters Su. The right hand brackets dicate that the S stands for the Silurian Period, the time when the rocks were formed. he u means that the rocks are undivided, that is they are not in easily separated layers. sing this example, you can work out what Om and Ou stand for.

Some geological maps have more than a dozen different kinds of rocks indicated by fferent shadings and explanatory letters.

Next, locate on the map the fossil site to which you want to go. Perhaps you want to hunt Devonian mussels and starfish. The geological map may not show the roads, such as the East-West Thruway, so you will have to consult a road map also. Having located the fossil site on the maps, decide the best way to go there.

Before you can find any Devonian starfish or mussels—or any other fossils—you must be able to recognize them. The best way to do this is to look at the fossils in a museum. If you can not find them in a museum, ask your geological survey for pictures of them. If they cannot send you any, ask them or a university paleontology department in what books you can find the pictures. Then, ask a librarian to help you get the books.

On Your Way Before going into the field, there is a warning you should heed. All the land in the United States is owned privately by a person or a company; or the land may belong to the government: local, state or federal. You may not wander around any piece of land that seems to be a good place to look for fossils; nor may you dig into any land that looks like a good fossil site. Any fossils you do find belong to the owner of the land in which they were buried.

All this sounds very discouraging, but it is not. It simply means that once you decide to hunt for fossils on a piece of land, you must ask the owner's permission to do so. Most of the time, the permission will be given cheerfully.

The embankments along railroad tracks and public roads are a good source of fossils, but they are owned by railroads or county or state governments. It is dangerous and unlawful

to dig into these embankments, because digging may start a landslide.

It is probably wisest to make one trip to find the fossil bed and a second trip to remove the fossils. The reason for two trips is this: on the first trip you should be free to wander around searching. You can do this best if you do not have to carry all the tools and materials that are needed to remove a fossil from its bed of rock or earth.

Although it is not wise to overburden yourself with equipment on a fossil trip, there are a few things you should take: a notebook and pencil, a compass for showing directions, a steel measuring tape at least twenty-five feet long, and a small spade. Two valuable tools that you will surely need are a geologist's, or Marsh, pick and an awl with a curved tip. You can buy a compass where Boy Scouts' equipment is sold, a steel measuring tape in a hardware store, and a geologist's

pick from a scientific supply house or from some mail-order companies. Awls are used for sewing heavy cloth, canvas, and carpeting. You should be able to buy an awl at a store that sells sewing supplies, at a sailmaker's shop, or at a rug shop. Awls are also used in making things of leather, so you should be able to buy one in a hobby shop or from a seller of shoemaker's supplies. Of course, on all trips you will take the geological maps and the road maps.

When you arrive at the fossil site, make a quick survey of the whole area, walking up and down its length and breadth. The purpose of the survey is to learn the limits of the fossil site, so that you can then make a careful, systematic search of it.

Once you have completed your survey, begin to search the fossil site carefully, walking up and down, back and forth, over every inch of it. As you cover the ground, look most carefully at the sides and bottoms of ravines, gullies, bluffs, or any other cut in the earth. Fossils frequently weather out of the material in which they are buried. Weathering out is the process in which weather—water, air, heat, freezing, thawing, wind—wears away rock, clay, sand, and gravel. The weathered-out fossils roll down to the bottom of the wall of earth or rock in which they were buried. The name given by paleontologists to fossils that have weathered out of the earth is *float.*

You will be searching an area in which other fossil hunters have found fossils, so keep an eye out for diggings they have left. It is a good bet to try digging near where others have dug.

When digging, take small spadefuls, pushing the spade

into the earth as gently as possible. Hard, quick strokes can break a fossil. Fossils are very fragile; they break easily at a touch. So, be careful.

Dig a trench a foot deep, lengthen it a few feet, then criss-cross it with another trench. Make the trenches wide enough to stand in, so that you can dig them a few feet deep. Go over your diggings, deepening them.

Inspect each spadeful of earth, especially if you are looking for small fossils, such as mussels and starfish. Also, keep your eyes open for fragments of the fossils you are looking for.

If your fossil site has fossils embedded in hard rock, look carefully at newly broken rock surfaces. You can identify these because their edges are sharper and less weathered than rocks that have broken long ago. If you find a fossil in a hard rock, simply mark its location. Removing fossils from hard rock is a difficult and delicate task. We will discuss how it is done, later in this book.

Write It Down When you have found a fossil, write in your notebook the exact location of the fossil bed (the ground in which the fossils are buried). Take your time. Write down *everything* you will need to know in order to return to the fossil bed. Give as many details as possible. In taking measurements, it is best to work backward from the fossil bed to the place where you entered the fossil site. For example, "30 feet east of twin pine trees, one leaning at a sharp angle downhill, and 12 feet from the top of bluff of brown clay and sand." Then, on to bigger measurements: "180 feet from road in a line perpendicular to the road. From this point, 250 yards to where road crosses Broken Bow Creek. East side of Highway

42, half mile from the 16-mile road marker."

When you have finished doing this, recopy your directions in reverse order, so that they direct you from road to fossil site. Add any things which you think may help you—or someone else—to find the fossil bed in the future. For instance, "Four birch clumps on west side of road, between Broken Bow Creek and the place to leave the road for the fossil bed," or "Two-story farmhouse about a quarter of a mile from 16-mile marker and on side of the fossil site."

Do not depend on your memory to lead you back to your fossil find. You may recall exactly where your fossils were located, if you are able to return tomorrow, next week, or even next month. But suppose you have to go back next year or later? You will find that the details will not return so easily after a span of time. So, write it all down!

One spring day, a Nebraska high-school biology class went on a field trip to collect insects. One boy found a piece of rock with peculiar markings on it. The marks looked like footprints of a bird, but they were in solid rock. The boy showed his find to one of his teachers. This teacher told the boy he had found a fossil, but showed no great interest. The boy put the chunk of rock into the knapsack in which he was carrying his lunch.

Four years later, the boy, now a sophomore at a midwestern university, showed the fossil to a professor in the university's paleontology department. The professor recognized the footprints as those of *Ornitholestes,* a tiny dinosaur, no bigger than a rooster. The professor wanted to go to the site where the rock had been found. He hoped to find more footprints or perhaps fossil bones of *Ornitholestes.* But try as

he would, the student could not remember exactly where he had picked up the footprint fossil. Now, after four years, he thought he had found it here . . . or perhaps a little farther off the road, there . . . or maybe over by that tree . . . or maybe not near this bend in the road at all. You may have this same trouble unless you do your remembering in a notebook.

A Tip Many an interesting fossil has been found in a stone fence. These are fences made by simply piling up slabs of stone without mortar to hold them.

If you decide to look for fossils in a stone fence, remember that the fence belongs to someone. Get his permission before you begin your search. Also, be sure to ask whether you may keep any fossils you find. Unless you do get permission to keep the fossils, they belong to whoever owns the fence. Afterward, put back the stones you have examined.

7 TAKING FOSSILS OUT OF THE EARTH

You have found a fossil site and have located fossils in it. Also, you have permission to dig. Now you must give some thought to the best way to remove the fossil from the earth, be it sand, gravel, clay, or rock. Before you make a move, remember that fossils are very old, and almost all are very fragile and brittle. They will split, shatter, or crumble if you do not handle them gently. Learn this, remember it, never let it out of your thoughts when handling fossils. Never!

Most fossils you find will be in fairly soft earth—sand, gravel, or clay. Many will have been unearthed by the action of weather. Perhaps you have located seashells at the foot

of a sandy bluff. You will find that rain and wind have uncovered some of the shells, which have rolled down to the bottom of the bluff. All you have to do is to pick them up.

When you pick up the shells, be careful. Handle them as if they are the thinnest of eggshells. Get a sturdy box, such as a shoe box or small packing carton. Line it with absorbent cotton, excelsior, shredded newspaper or some other soft material. Put the fossils in the box, separating them so that they do not touch. Cover them with more of the soft material, close the box, and secure the cover with string or adhesive tape. Take the box home, carrying it gently.

Never In the Field Never try to prepare a fossil in the field. This is a very important rule that paleontologists follow, and you should follow it, too. When paleontologists speak of preparing a fossil, they mean preparing it for display; taking it out of whatever earth it is found in, cleaning it, putting broken parts together, restoring missing parts, and making it ready for show. Very delicate tools are needed for preparing a fossil, as well as a considerable amount of other equipment and materials. There is no sense in carrying all these things to the fossil site. And it is just too easy to break a fossil when trying to prepare it with nothing but field tools.

If the fossil you find has not weathered out of the earth, you must dig it out. This is not as easy as it sounds.

If you see a fossil bone or shell sticking out of gravel, sand, or clay, don't try to dig it out with a shovel or trowel. The buried part of the fossil may not be located where you think it is. If you plunge a steel blade into the earth, you may strike the buried part and shatter it. Also, a single bone may

indicate that the rest of the skeleton is buried just below. The shovel or trowel will then break other bones of the skeleton.

Using your awl, you pick and scrape away the material in which the fossil is buried. You not only pick at it slowly, you pick gently. After you have scraped and picked some earth loose, gently brush it away. Continue to do this until you have freed the whole fossil. This may take hours; indeed, it probably will.

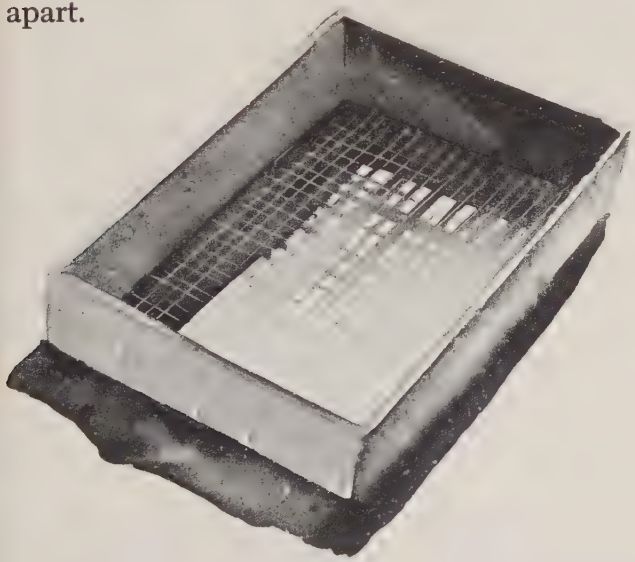
A Wash Out Some fossil beds contain thousands of fossils. You may come upon such a fossil bed in gravel or clay. If you find large numbers of small fossils—teeth, jawbones, and other bones of small animals—and you wish to collect these, you may break the rule against digging. If many fossils are available, it may be worth taking a chance on breaking some, in order to collect others more easily.

Make one or more wooden boxes like the one shown in the illustration. This box is easy to make. It may be square or rectangular, as you wish. Cut the sides of the box from a plank about three-quarters of an inch thick and ten inches to one foot wide. Nail the sides together using either finishing nails or roofing nails.

The strip of wood that runs diagonally across the top is about one and one-half inches wide and three-quarters of an

inch thick. Nail it to the box using at least four nails at each end. This crosspiece will not only stiffen the structure of the box, it can also be used as a handle for lifting the box.

The bottom of the box is screening. Copper fly screening will do. For strength, use a doubled-over piece. Snip off a half-inch square from each corner and fold over flat toward the center a half inch of each side. Nail the screening to the box with copper tacks, spacing them a quarter of an inch apart.

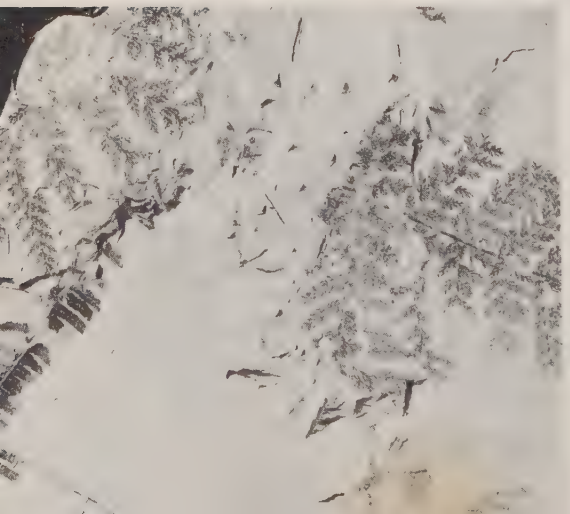


Fill the box half full of the clay or gravel and put it in water. After the box has soaked for a while, swish it up and down in order to make the water run through the screen. Do this until all, or almost all, the clay or gravel has washed out through the screen. Better yet, anchor the box in a running stream. The water-loosened clay and the gravel should be washed away by the moving water. When you see that

no more material is washing out of the box, take it out of the water and let it dry. When the box is dry, gently dump the contents on a table. Throw away the pebbles and any undissolved lumps of gravel or clay. It might be a good idea to open a few lumps gently to see if they contain anything interesting. Finally, sort the remaining material, picking out the fossils.

Fossils Out of Rock Suppose you find fossils in hard rock. Getting them out is the biggest challenge to a paleontologist. What do you do? If you have never gone on a field trip with a paleontologist who has shown you how to remove fossils from rock, you had better call for help. Make careful notes so that you can find the fossil a second time. Make a drawing or take a photograph of the fossil.Try to determine what kind of rock it is in. Then send all this information to the museum or university paleontology department near where you found the fossil. If you can get the experts interested, they will come to the fossil site to help you remove the fossil.

They will do something like this. If the fossil is dry, they



will spray it with plastic cement that is sold under the name of Krylon. Or they may paint the fossil with shellac mixed with an equal amount of alcohol. If the fossil is damp, it will be painted with a material called gum arabic, which has been dissolved in water. These steps will strengthen the fossil, so that some of the rock may be cut away.

The rock is cut with cold chisels struck with hammers. It is chipped away at some distance from the fossil. Only experience will tell you the proper distance. The cuts in the rock should always be made *away* from the fossil. The rock must be cut under or completely around, so that a piece of rock containing the fossil can be lifted out. While hammering or chipping rock, the paleontologist wears goggles or sunglasses and a hat, usually a hard hat like that of a construction worker.

The paleontologist continues to chip and scrape away the rock, exposing the fossil. As parts of the fossil appear, they are covered with rice paper (or tissue paper or facial tissue) soaked in gum arabic and water. This keeps the fossil from crumbling.

wo ways to prepare a fossil. At left, the fossil fern, after some eaning, appears just about as it did when it was found in the field. t right, the rock surrounding the fossil crinoid, or sea-lilly animal, as been painstakingly chipped, picked, ground, scraped, and rushed away.

As more and more of the fossil is exposed, the whole section of rock and fossil is strengthened by putting it into a cast. The cast is made by soaking strips of burlap in a paste of plaster of paris. The wet strips are placed on the fossil and the rock, and are allowed to dry. Several layers, alternating in crosswise fashion, are put on. The dried plaster strips make a cast like one that a doctor puts on a broken arm or leg.

The partially exposed fossil and the chunk of rock it is in are taken to a laboratory for final preparation.

Back Home In your home or a laboratory, the final preparation begins. If the fossil is encased in plaster of paris, the cast can be removed by wetting it and peeling it off layer by layer. The rice paper and gum arabic can be removed by soaking with alcohol. When this strengthening material has been removed, you are ready for the hardest part of a fossil collector's job. You must remove the fossil from the rock.

First give the fossil another painting with shellac in alcohol. Then, using awl, small chisels, and tweezers, chip and pick away the rock. This will take time, very much time. Begin to chip away the rock at its outer edges, working in toward the fossil. Take *small* chips from the rock. Be patient. Eventually, you will work your way close to the fossil. When you are close, scrape the rock away and pick tiny pieces at a time. In the end, you will have to use a magnifying glass to see the last pieces of rock nearest the fossil.

It did take a long time—months and months—didn't it? Well, console yourself by remembering that to prepare the skeleton of *Brontosaurus* that is in the Hall of Dinosaurs of the Ameri-

can Museum of Natural History, paleontologists worked fifteen years!

As a fossil hunter, you may want to remember something a great American paleontologist, Henry Fairfield Osborne, said: "The hunter of live game is always bringing live animals nearer death and extinction, whereas the fossil hunter is always seeking to bring extinct animals to life."

In its history, the horse has had many forms. Starting at the lower left and going aro to the right are the known ancestors of the modern horse. The small animal at the lo left is the first ancestor of all horses. It is an eohippus, or "dawn horse," which lived al 50 million years ago. It was the size of a large cat and, instead of hoofs, had four toe each front foot and three on each hind foot.

Fifteen million years later, the next ancestor roamed the plains. It was mesohip which was about as large as a Doberman-pinscher dog, and still had toes.

Within ten million years, horses as large as ponies were fleeing saber-toothed These horses had three toes on each foot, but only one, the large center toe, touched ground. The scientific name of this ancestor is merychippus.

Another eight million years and the big toes had become hoofs. This horse, pliohippus, was almost as large as most horses living today.

A million years ago equus, a short-faced, short-maned, wiry kind of modern h ran swiftly over the Texas prairies.

Finally, man began to breed horses, and many new sizes and kinds of horse developed. One looked like the handsome specimen of equus at the top of this picture.

APPENDIX A

These books will help you to identify rocks.

Fenton, Caroll L., and Mildred Fenton, *The Rock Book*. New York. Doubleday. 1940.

Fenton, Caroll L., *The Fossil Book*. New York, Doubleday. 1966.

Gallant, Roy, and C. J. Schuberth. *Discovering Rocks and Minerals*. New York. Doubleday The Natural History Press. 1967.

Pearl, Richard M., *Rocks and Minerals*. Everyday Handbook Series. New York. Barnes and Noble.

Pough, Frederick. *A Field Guide to Rocks and Minerals*. Boston. Houghton Mifflin. 1953.

Do not be afraid to look into college geology textbooks. They are a lot easier to understand than you may think. In particular, the pictures are usually good. Two excellent texts are:

Leet, L. Don, and Sheldon Judson. *Physical Geology*. Englewood Cliffs, New Jersey. John Wiley & Sons. 3rd edition. 1965.

Hurlbut, Cornelius, Jr. *Dana's Manual of Mineralogy*. Englewood Cliffs, N. J. John Wiley & Sons. 17th edition. 1961.

A book listing fossil locations in the United States is:

Murray, Marian. *Hunting for Fossils*. New York. Macmillan. 1967.

APPENDIX B

These are some of the museums that have displays of fossils. This is not meant to be a complete list, because almost all natural history museums have some fossils to show.

ALASKA

Alaska Historical Library and Museum, Juneau.

CALIFORNIA

California Academy of Sciences, Golden Gate Park, San Francisco.

Riverside Municipal Museum, Riverside.

Santa Barbara Museum of Natural History, 2559 Puesta del Sol Road, Santa Barbara.

University of California Museum of Paleontology, Earth Sciences Building, Berkeley.

COLORADO

Canon City Municipal Museum, Canon City.

Denver Museum of Natural History, Denver.

Gem Village Museum, Bayfield.

University of Colorado Museum, Boulder.

CONNECTICUT

Peabody Museum of Natural History, Yale University, New Haven.

Stamford Museum and Nature Center, Stamford.

Trinity College Museum, Hartford.

DISTRICT OF COLUMBIA

Smithsonian Institution, Museum of Natural History, United States National Museum, Washington.

FLORIDA

Central Florida Museum, Orlando.

University of Florida State Museum, Gainsville.

IDAHO

Idaho State University Museum, Pocatello.

ILLINOIS

Chicago Academy of Sciences, Chicago.
Chicago Natural History Museum, Chicago.
Illinois State Museum of Natural History and Art, Springfield.
Illinois State Normal University Museum, Normal.
Field Museum of Natural History, Chicago.
University of Illinois Museum of Natural History, Springfield.

INDIANA

Department of Geology, DePauw University, Greencastle.
Department of Geology and Botany, Indiana University, Bloomington.
Department of Geology, University of Notre Dame, Notre Dame.
Wabash County Historical Society Museum, Wabash.

IOWA

Grout Historical Museum, Waterloo.

KANSAS

Fort Hays Kansas State College Museum, Hays.
University of Kansas Museum of Natural History, Lawrence.

KENTUCKY

Louisville Museum, Louisville.
Kentucky Museum, Bowling Green.
Department of Geology, University of Louisville, Louisville.

LOUISIANA

Louisiana State University Department of Geology Museum, Baton Rouge.

MAINE

Nylander Museum, Caribou.

MARYLAND

Maryland Academy of Sciences, Baltimore.
Natural History Society of Maryland, Baltimore.

MASSACHUSETTS

Harvard University Museum of Comparative Zoology, Cambridge.
University of Massachusetts Scientific Collection, Amherst.

MICHIGAN

University of Michigan Museum of Paleontology, Ann Arbor.

MINNESOTA

St. Paul Institute Science Museum, St. Paul.

MISSOURI

State Museum of Natural Resources, Jefferson.

MONTANA

Fort Peck Project, Fort Peck.

NEBRASKA

Cook Museum of Natural History, Agate.
University of Nebraska State Museum, Lincoln.
University of Nebraska Trailside Museum, Fort Robinson.

NEVADA

Ichthyosaur State Park, Nye County.

NEW HAMPSHIRE

Dartmouth College Museum, Hanover.

NEW JERSEY

New Jersey State Museum, State House Annex, Trenton.
Princeton University Museum, Princeton.
Rutgers University Geological Museum, New Brunswick.

NEW MEXICO

Natural History Museum, Carlsbad Caverns National Park, Carlsbad.

NEW YORK

American Museum of Natural History, New York City.
New York State Museum, Albany.

NORTH CAROLINA

Research Laboratories of Anthropology, University of North Carolina, Chapel Hill.

OHIO

Cincinnati Museum of Natural History, Cincinnati.

Cleveland Metropolitan District Trailside Museum, Cleveland.

Cleveland Museum of Natural History, Cleveland.

Ohio State University Geological Museum, Columbus.

University of Cincinnati Museum, Cincinnati.

OKLAHOMA

Museum of Great Plains, Lawton.

Stovall Museum, University of Oklahoma, Norman.

OREGON

Oregon Museum of Science and Industry, Portland.

University of Oregon Museum of Natural History, Eugene.

PENNSYLVANIA

Academy of Natural Sciences of Philadelphia, Philadelphia.

Carnegie Museum, Pittsburgh.

SOUTH DAKOTA

South Dakota School of Mines and Technology Museum of Geology, Rapid City.

Zeitner Geological Museum, Mission.

TEXAS

El Paso Centennial Museum, Texas Western College, El Paso.

Big Bend Historical Museum, Sul Ross State College, Alpine.

Dallas Museum of Natural History, Dallas.

Panhandle Plains Historical Museum, Canyon.

Department of Geology, Southern Methodist University, Dallas.

Texas Memorial Museum, Austin.

West Texas Museum, Texas Technological College, Lubbock.

University of Houston Geological Museum, Houston.

University of Texas Memorial Museum, Baird.

UTAH

Bryce Canyon National Park, Bryce Canyon.
Dinosaur Quarry Visitor Center, Dinosaur National Monument, Jensen.
University of Utah Museum of Natural History, Salt Lake City.

WASHINGTON

Gingko Petrified Forest State Park,Vantage.

WISCONSIN

Thomas A. Greene Memorial Museum, Milwaukee-Downer College, Milwaukee.
Milwaukee Public Museum, Milwaukee.

WYOMING

Wyoming State Museum, Cheyenne.
University of Wyoming Geological Museum, Laramie.

APPENDIX C

Some colleges and universities that have paleontology departments.

Amherst College, Amherst, Massachusetts.
University of Arizona, Tucson, Arizona 85702
University of California, Berkeley, California 94704
University of Chicago, Chicago, Illinois
Columbia University, New York, N.Y. 10027
Dartmouth College, Hanover, New Hampshire
University of Florida, Gainsville, Florida
Harvard University, Cambridge, Massachusetts
University of Kansas, Lawrence, Kansas
University of Michigan, Ann Arbor, Michigan
University of Nebraska, Lincoln, Nebraska 68501
Princeton University, Princeton, New Jersey
South Dakota School of Mines and Technology, Rapid City, South Dakota
University of Texas, Austin, Texas 78710
University of Wyoming, Laramie, Wyoming
Yale University, New Haven, Connecticut 06510

APPENDIX D

GEOLOGICAL SURVEYS

ALABAMA *Geological Survey of Alabama, P.O. Drawer O, University, Ala.*

ALASKA *State Division of Mines and Minerals, Territorial Building, Box 1391, Juneau, Alaska 99801*

ARIZONA *College of Mines, Arizona Bureau of Mines, University of Arizona, Tucson, Arizona 85725*

ARKANSAS *Arkansas Geological and Conservation Commission, State Capitol, Little Rock, Arkansas 72201*

CALIFORNIA *Division of Mines and Geology, Department of Conservation, Ferry Building, San Francisco, California 94111*

COLORADO *Colorado Metal Mining Fund Board, 204 State Office Building, Denver, Colorado 80202*

CONNECTICUT *Connecticut Geological and Natural History Survey, Judd Hall, Wesleyan University, Box 128, Wesleyan Station, Middletown, Connecticut 06457*

DELAWARE *Delaware Geological Survey, University of Delaware, Newark, Delaware 19711*

FLORIDA *Florida Geological Survey, P.O. Box 631, Tallahassee, Florida 32302*

GEORGIA *Department of Mines, Mining, and Geology, State Division of Conservation, 19 Hunter Street S.W. Atlanta, Georgia 30303*

IDAHO *Idaho Bureau of Mines and Geology, University of Idaho, Moscow, Idaho 83843*

ILLINOIS *State Geological Survey Division, 121 Natural Resources Building, University of Illinois, Urbana, Illinois 61801*

INDIANA *Indiana Geological Survey, Department of Conservation, Owen Hall, Indiana University, Bloomington, Indiana 47401*

IOWA *Iowa Geological Survey, Geology Annex, Iowa City, Iowa 52240*

KANSAS *State Geological Survey, University of Kansas, Lawrence, Kansas 66045*

KENTUCKY *Kentucky Geological Survey, 307 Mineral Industries Building, 120 Graham Avenue, Lexington, Kentucky 40506*

LOUISIANA *Louisiana Geological Survey, P.O. Box 8847, State University, Baton Rouge, Louisiana 70803*

MAINE *Department of Economic Development, Division of Geology, State House, Augusta, Maine 04330*

MARYLAND *Department of Geology, Mines, and Water Resources, 102 Latrobe Hall, Johns Hopkins University, Baltimore, Maryland 21218*

MICHIGAN *Geological Survey Division, Department of Conservation, Lansing, Michigan 48926*

MINNESOTA *Minnesota Geological Survey, University of Minnesota, Minneapolis, Minnesota 55414*

MISSISSIPPI *Mississippi Geological, Economic, and Topographical Survey, 2525 North West Street, P.O. Drawer 4915, Jackson, Mississippi 39206*

MISSOURI *Division of Geological Survey and Water Resources, P.O. Box 250, Rolla, Missouri 65401*

MONTANA *Montana Bureau of Mines and Geology, Montana School of Mines, Butte, Montana 59701*

NEBRAKSA *Conservation and Survey Division, Nebraska Hall, University of Nebraska, Lincoln, Nebraska 68508*

NEVADA *Nevada Bureau of Mines, University of Nevada, Reno, Nevada 89507*

NEW HAMPSHIRE *New Hampshire State Planning and Development Commission, Conant Hall, University of New Hampshire, Durham, New Hampshire 03824*

NEW JERSEY *Department of Conservation and Economic Development, Bureau of Geology, 520 East State Street, Trenton, New Jersey 08625*

NEW MEXICO *State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801*

NEW YORK *Geological Survey, State Education Building, Hawk Street, Albany, New York 12224*

NORTH CAROLINA *Division of Mineral Resources, Department of Conservation and Development, State Office Building, Raleigh, North Carolina 27601*

NORTH DAKOTA *North Dakota Geological Survey, University of North Dakota, Grand Forks, North Dakota 58201*

OHIO *Ohio Division of Geological Survey, 1207 Grandview Avenue, Columbus, Ohio 43212*

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The states not included in this list do not have a geological survey or other department of the same kind.

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